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TPF Coronagraph Integrated Modeling Results

Scott Basinger, Andrew Kissil, William Ledeboer

Jet Propulsion Laboratory, California Institute of Technology

Pasadena, CA 91109

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Introduction

- Quick look at models
  - Structural (Finite Element Model)
  - Optical
- Jitter analysis: Structural and optical response due to Reaction Wheel Assembly (RWA) perturbations
  - Rigid body effects
  - Primary mirror distortions
- Steady state thermal effects due to 180 degree roll of spacecraft
  - Primary mirror temperatures and distortions
  - Optical wavefront

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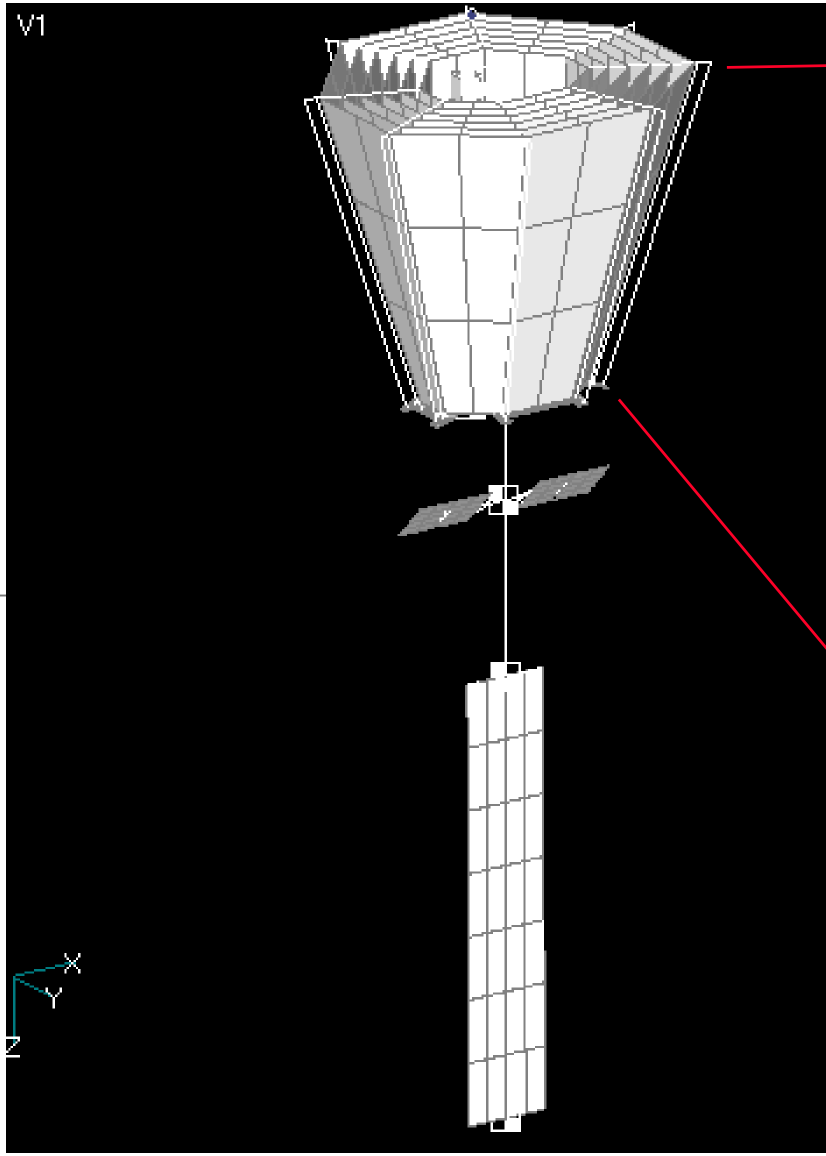
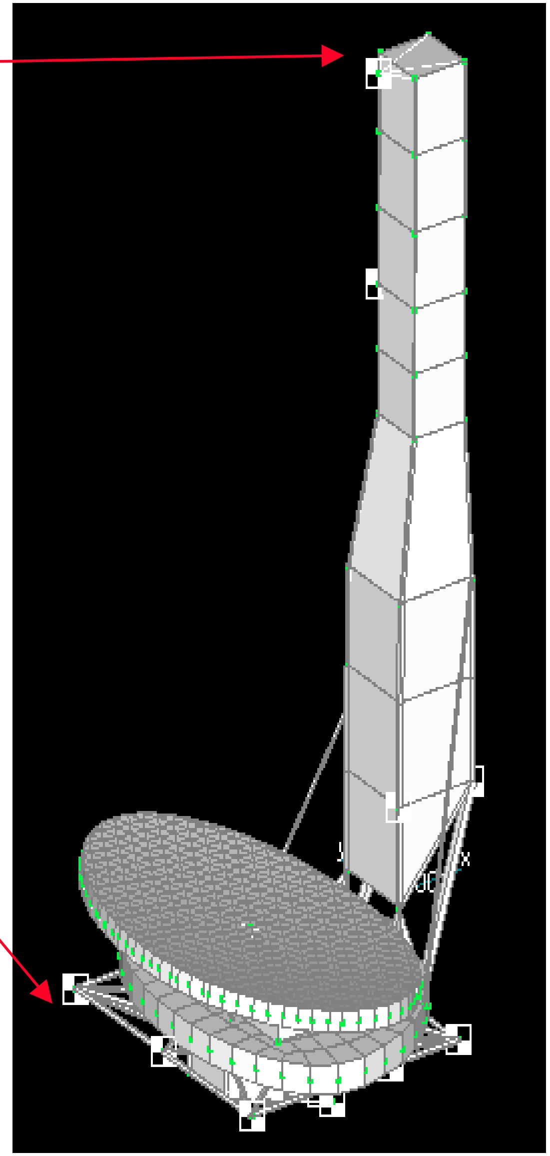
Structural Finite Element Model





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Model Plots of Primary & Secondary Sub-Assemblies

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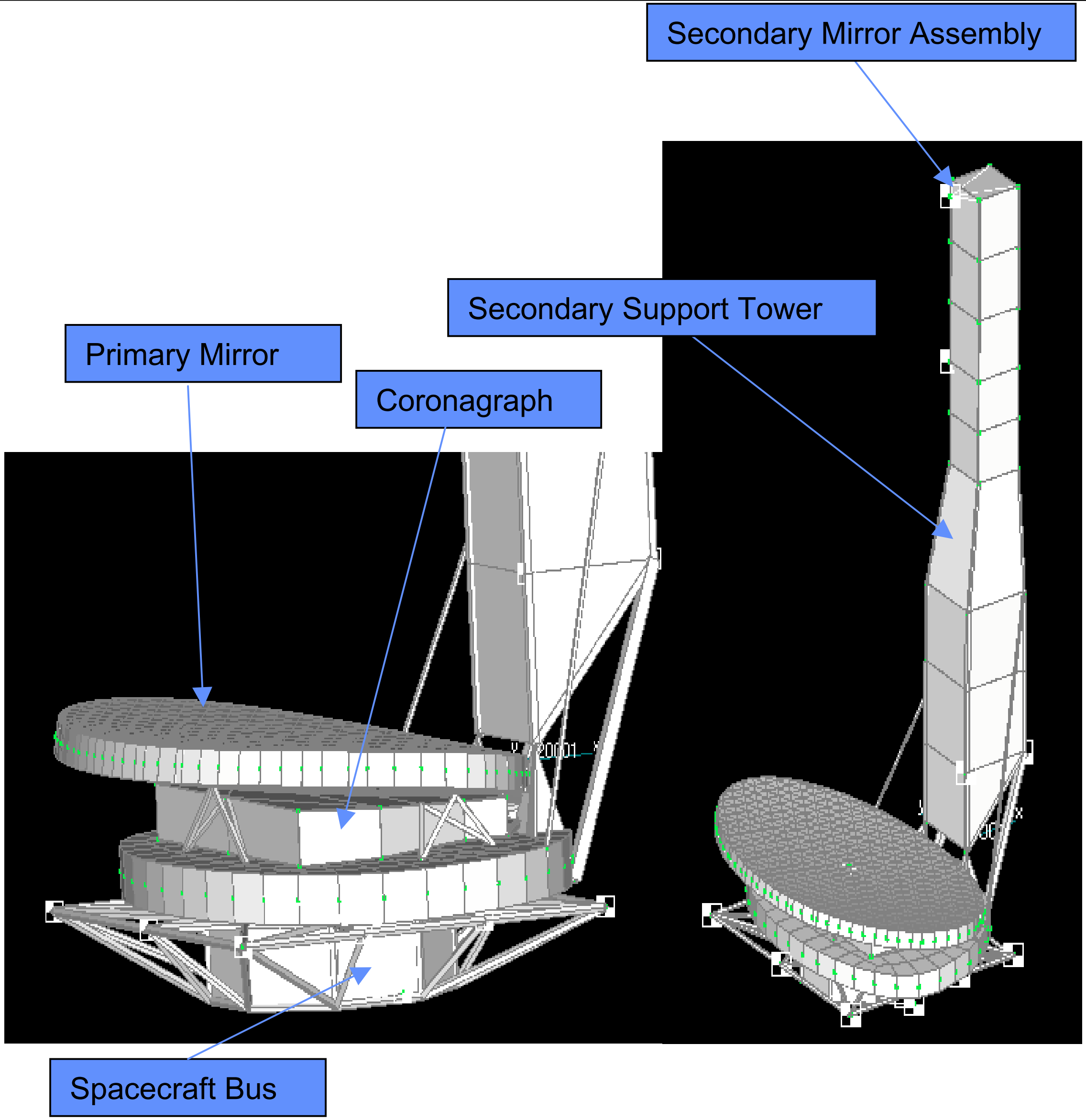

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Structural Model Summary

- **Components and Assumptions**
  - 6 x 3.5 m Primary Mirror
    - ULE Glass (E= 68 Gpa, rho= 2200 kg/m^3, CTE= .03 ppm/K)
  - 10 m Long Secondary Support Tower
  - 1 Hz Passive Isolation between Payload & Spacecraft
    - Input for Reaction Wheel Jitter Assumes 2nd Level of Isolation at RW Assembly Mount (.1N, .01Nm)
  - 0.5% Uniform Passive Damping Assumed (Conservative)
    - Will Look at Increased Damping for Critical Modes
  - 6 V-groove Layer Sunshield (2 mil Kapton)
    - 3 psi membrane tension preload (geom stiff modeled with equiv shear props)
  - Solar Array (4 Panels)
  - Solar Sail (2 mil Kapton, 17 x 3.3 m, sized by Doug Lisman for 48 Hr between RW offloads)
    - 6 psi membrane tension preload (geom stiff modeled with equiv shear props)
  - Predominant Material = Quasi-Iso M55J GrEp (E= 110 GPa, rho= 1633 kg/m^3, CTE= -.18 ppm/K)
- **Model Statistics**
  - System Dynamic Model: 1397 Nodes (~8,380 dofs), & 1888 Elements
  - Primary Mirror Mid-Fidelity Model (for thermal def): 2100 Nodes (~12,600 dofs), & 4600 Elements
    - 2 Layers of Plate Elements for Front/Back Facesheets & Orthotropic Solids for Core
  - Total Deployed Mass = 3,260 kg (cg= 0.86 m forward of RW Location)
    - 650 kg Primary Mirror, 250 kg Secondary Support Tower, 15 kg Secondary, 550 kg AMS

Frequency vs Modes of Model

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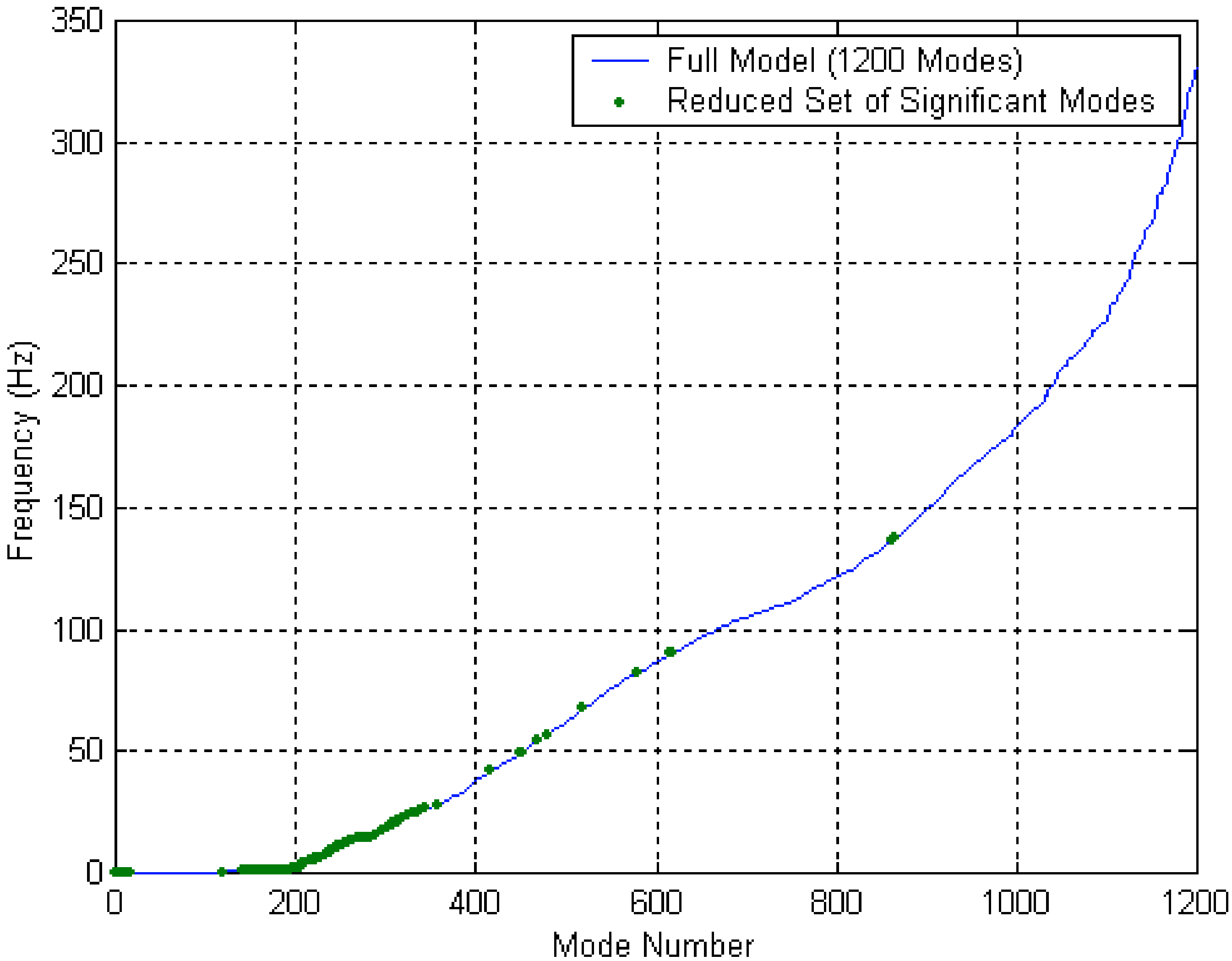

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Vibration Mode Analysis Results

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- Highest rigid body mode is 1.7×10^{-5} Hz (indicates good rigid body behavior- i.e. no grounding)
- Lowest system elastic mode is at 0.126 Hz (due to solar sail)
- Lowest sunshield mode is at 0.25 Hz
- Lowest solar array mode is at 1.1 Hz
- Lowest secondary tower mode is at 21 Hz

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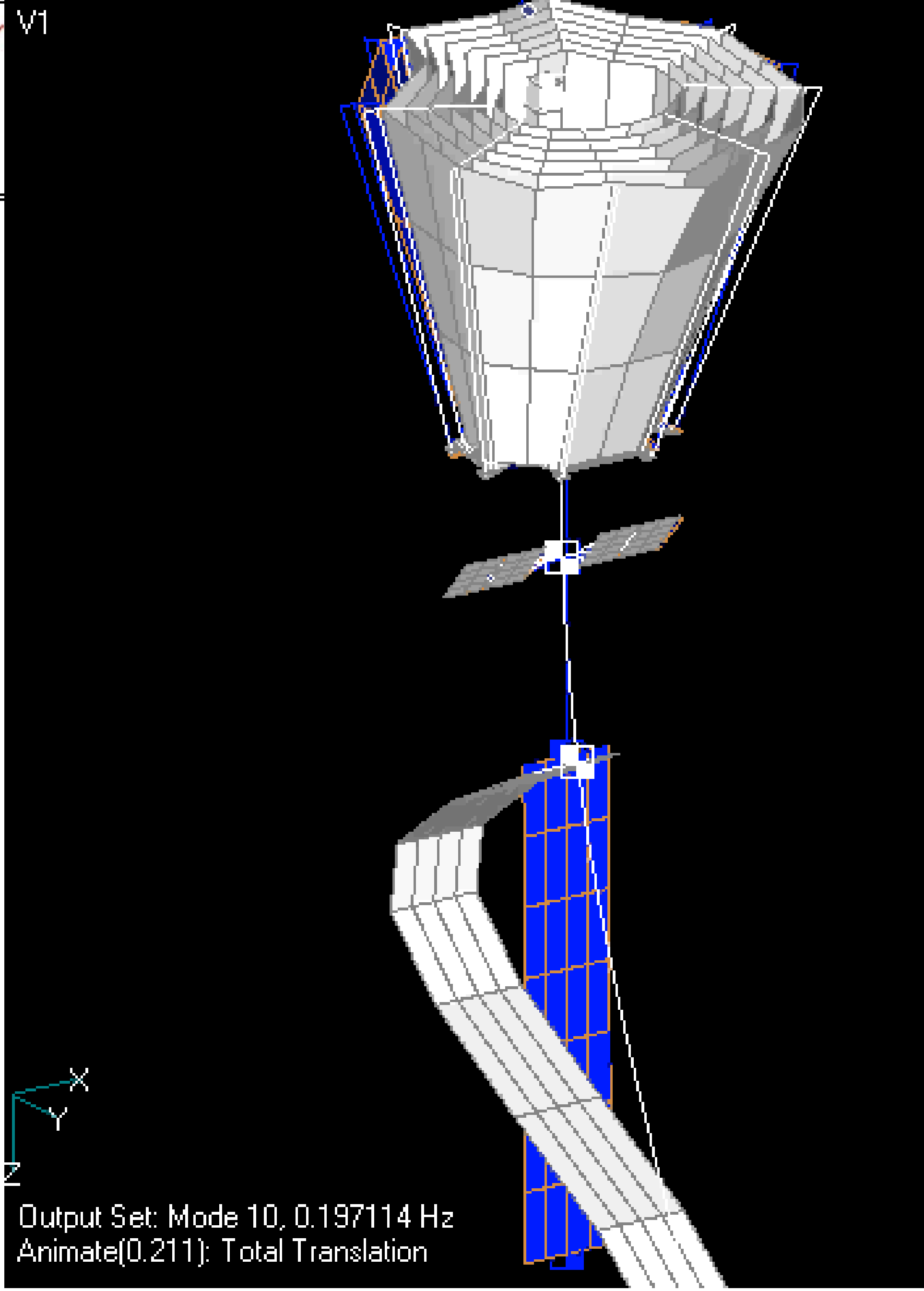
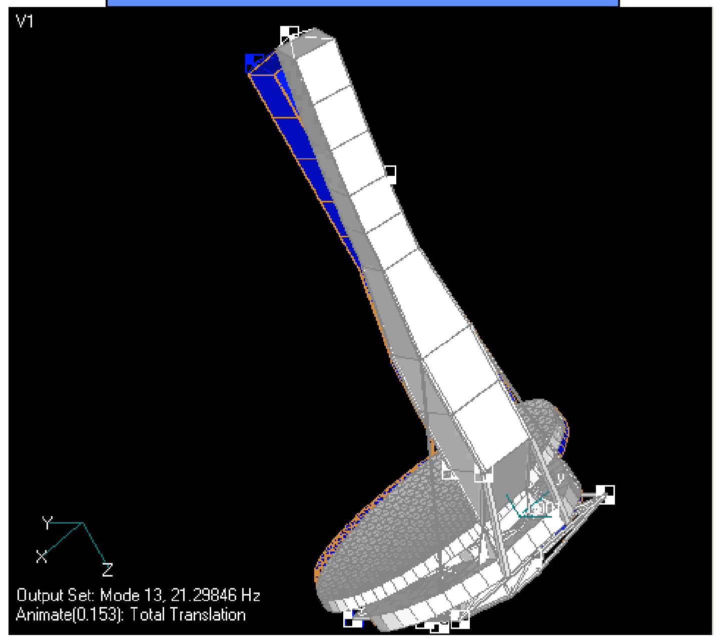


First Secondary Mirror Tower Bending/Torsion Mode (21 Hz)



Magnified Displacements for Vib Mode 10 (.2 Hz)

Optical Model Layout

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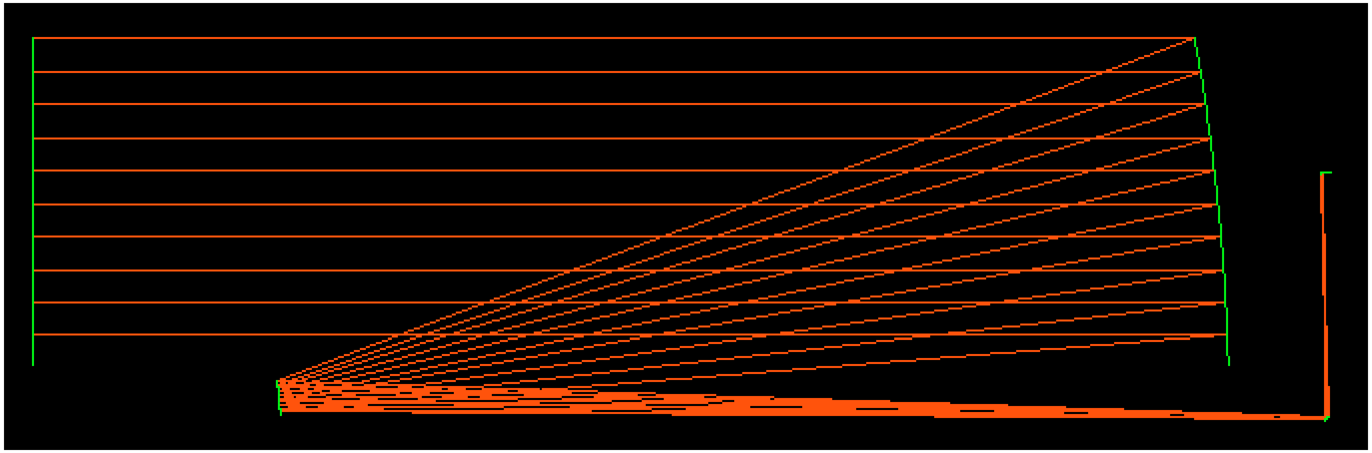
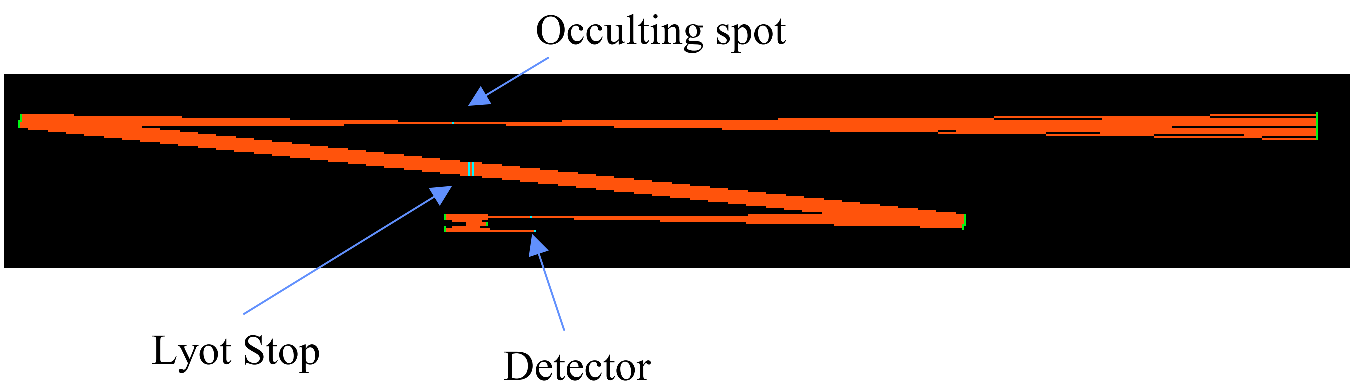
6m x 3.5m Telescope



Optical Bench (coronagraph)



Optical Model Summary

- For the *integrated* modeling results (only), ray tracing is used
- Tilt is removed from wavefront
- Wavefront is computed at the "exit pupil" of the occulting spot
- Sensitivity matrices were generated by perturbing each degree of freedom individually
  - 6 dof rigid body of each optic
  - primary mirror distortions

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Jitter analysis

(Reaction Wheel Assembly perturbation effects)

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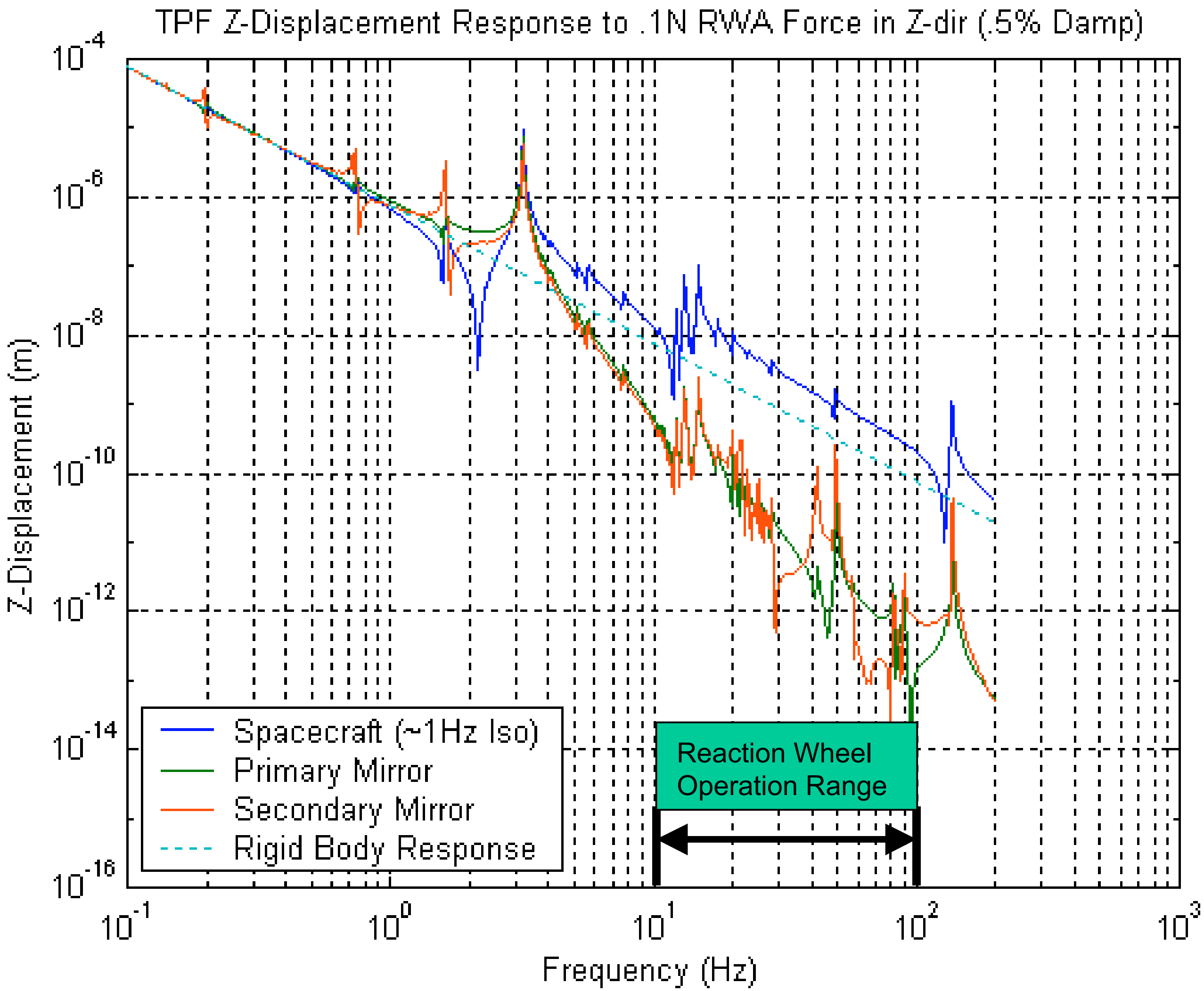
Jitter Analysis



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Jitter Analysis

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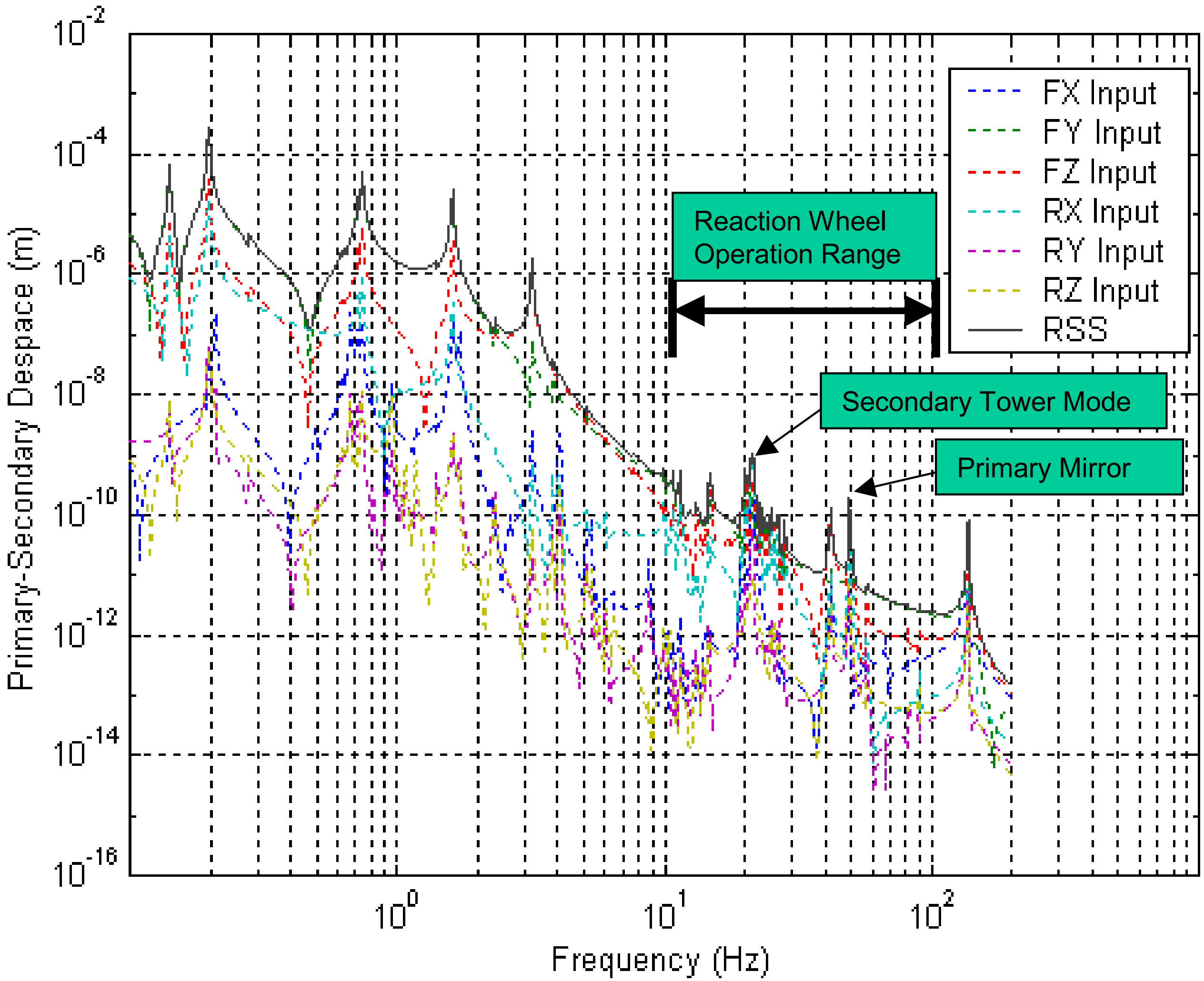
M1-M2 Despace Frequency Response to Simplified RW Jitter



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Jitter Analysis

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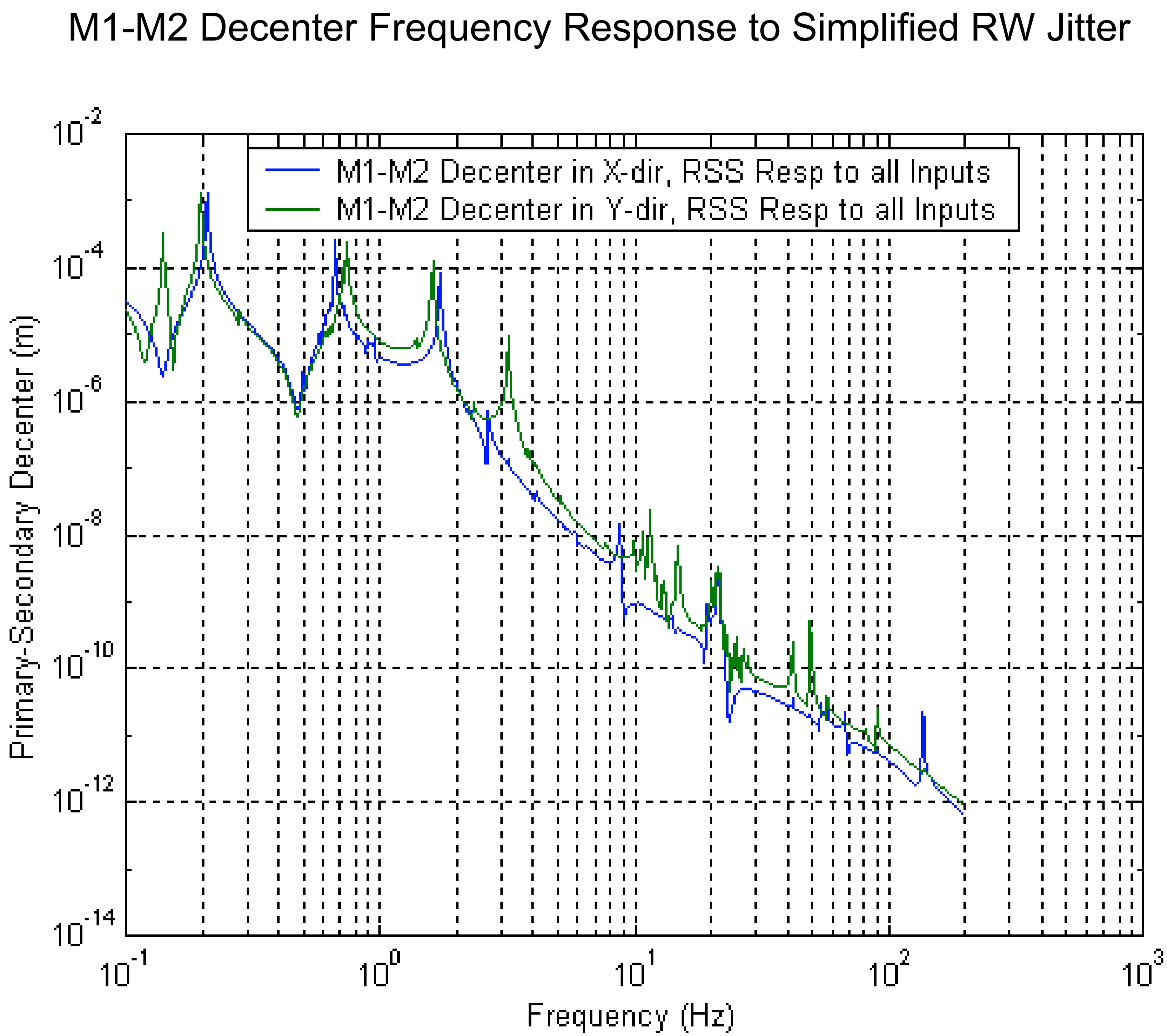
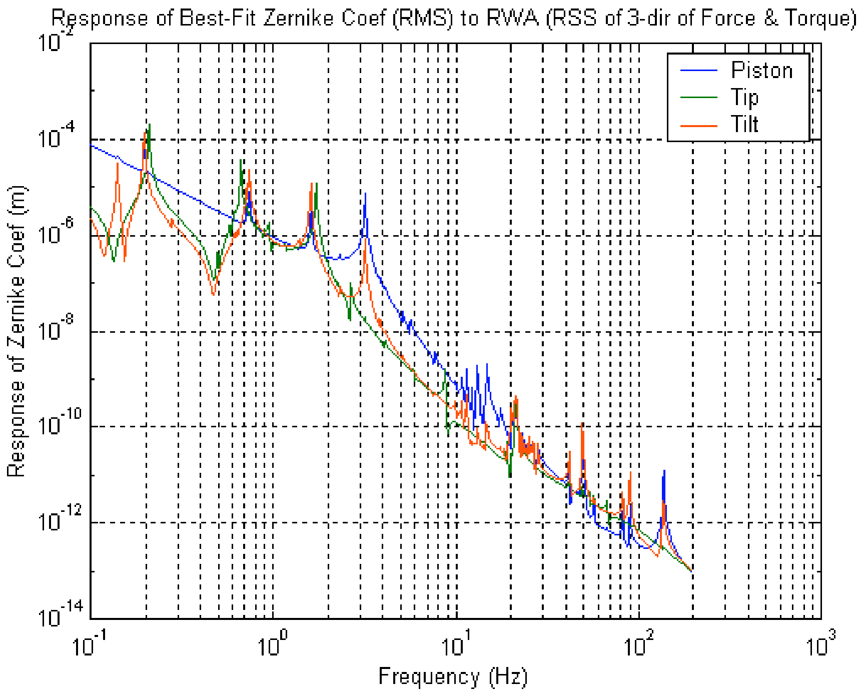
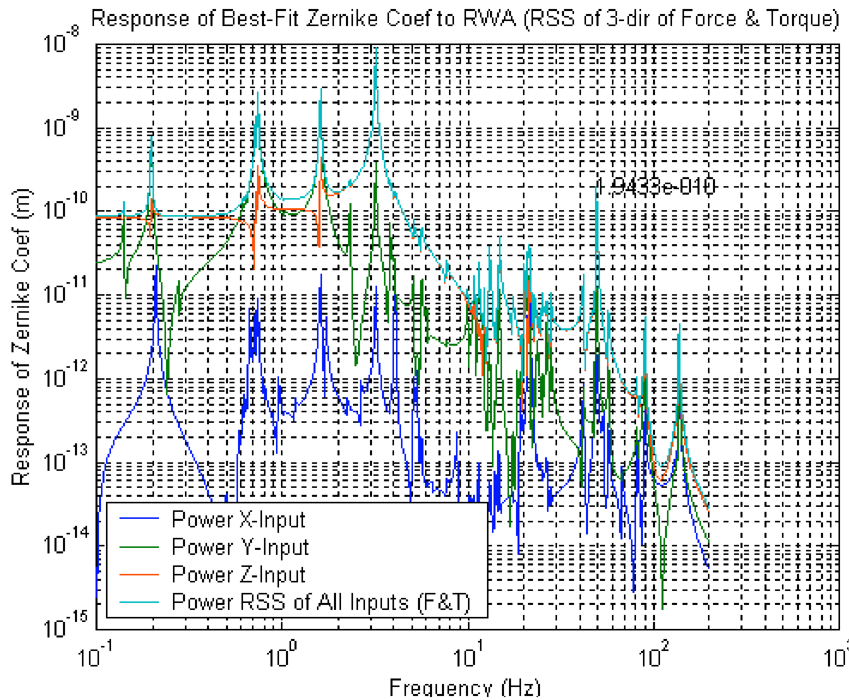
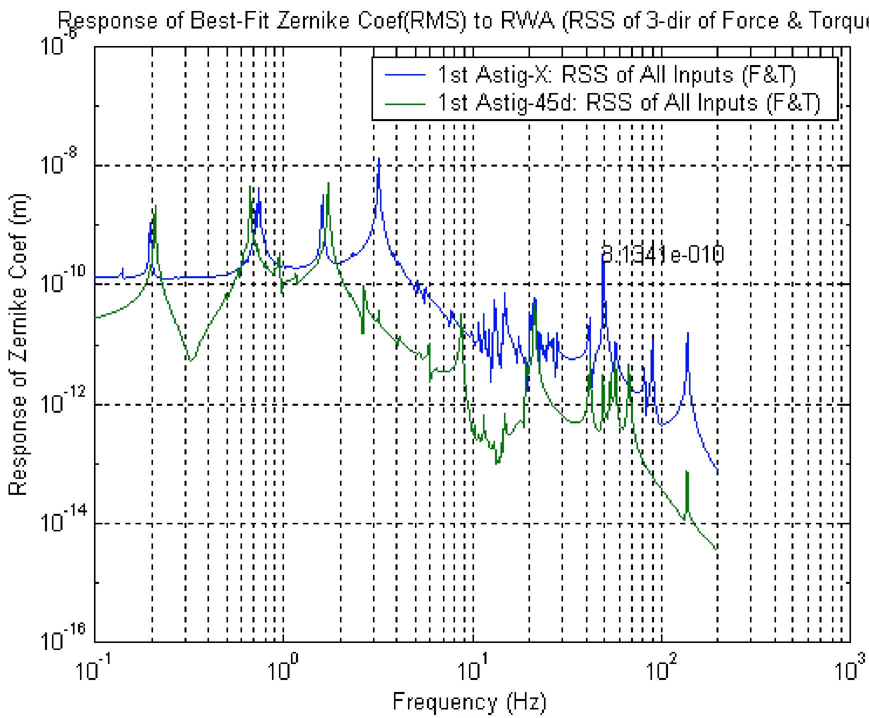
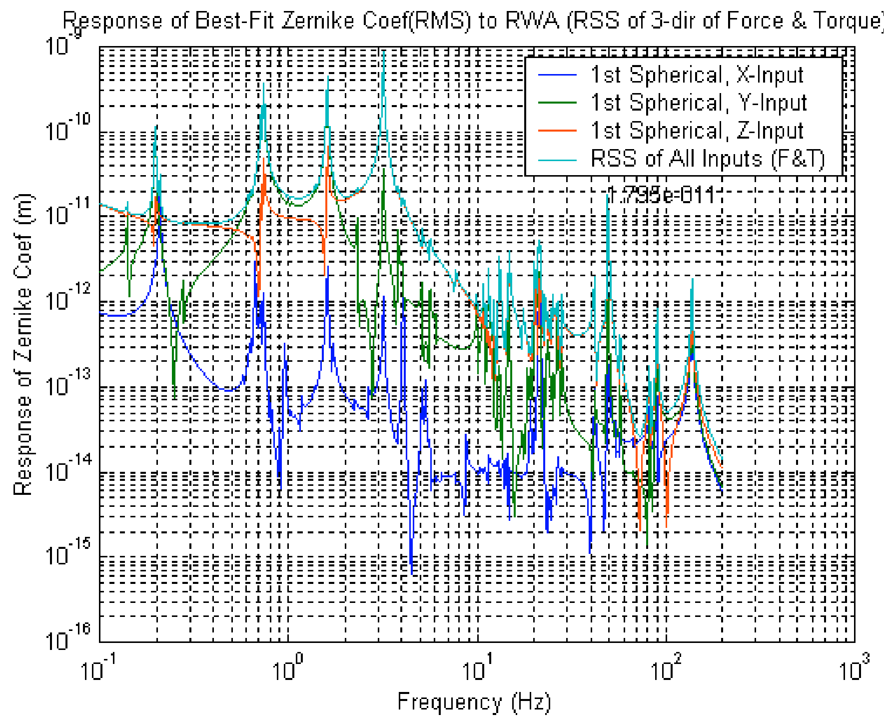


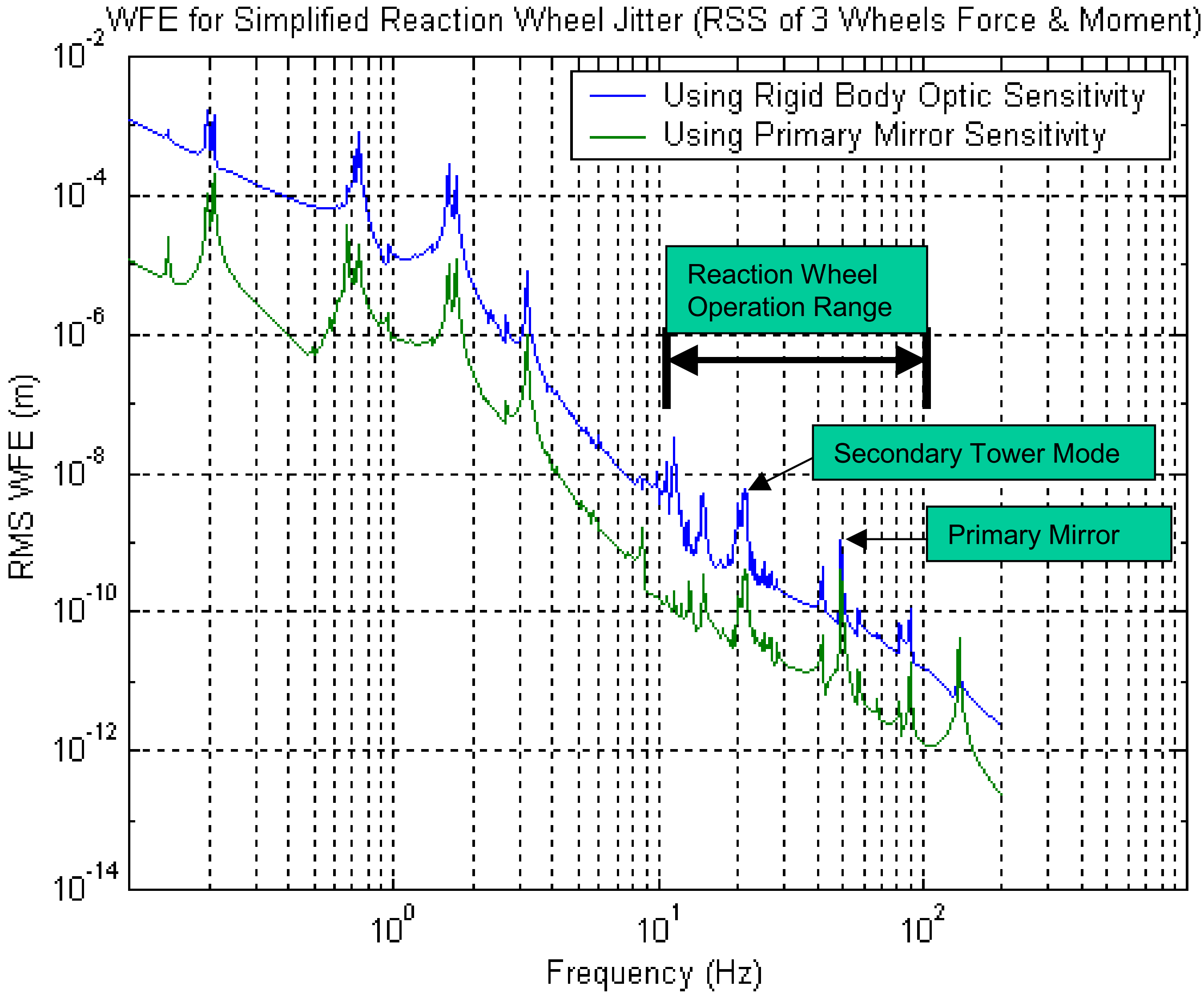

Response of Best-Fit Zernike Coef (RMS) to RWA (RSS of 3-dir of Force & Torque)
Piston
Tip
Tilt
Response of Zernike Coef (m)
Frequency (Hz)


Response of Best-Fit Zernike Coef to RWA (RSS of 3-dir of Force & Torque)
1.9433e-010
Power X-Input
Power Y-Input
Power Z-Input
Power RSS of All Inputs (F&T)
Response of Zernike Coef (m)
Frequency (Hz)


Response of Best-Fit Zernike Coef(RMS) to RWA (RSS of 3-dir of Force & Torque)
1st Astig-X: RSS of All Inputs (F&T)
1st Astig-45d: RSS of All Inputs (F&T)
3.1341e-010
Response of Zernike Coef (m)
Frequency (Hz)


Response of Best-Fit Zernike Coef(RMS) to RWA (RSS of 3-dir of Force & Torque)
1st Spherical, X-Input
1st Spherical, Y-Input
1st Spherical, Z-Input
RSS of All Inputs (F&T)
1.795e-011
Response of Zernike Coef (m)
Frequency (Hz)

Optical response to Jitter



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RW Jitter Analysis Results Summary

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Two Types of SC/Telescope Isolation considered: 1Hz Passive & Active*

Rigid Body Optic Response (Model v2c)

Description	RMS WFE1 Passive Damp	RMS WFE2 Acive Damp	Req	WFE2/Req
M1-M2 Despace (nm)	1.0	0.01	2	0.006
M1-M2 Decenter (nm)	22.9	0.29	8	0.036
M2 Rotation (nrad)	2.8	0.04	5	0.007

Primary Mirror Distortion Response (picometers, Model v2c)

Zernike	Descr	RMS WFE1 Passive Damp	RMS WFE2 Active Damp	Req	WFE2/Req
4	Power	194	2.43	5	0.5
5	1st Ast 45	47	0.59	10	0.1
6	1st Ast X	313	3.91	5	0.8
7	1st Coma Y	11	0.14	10	0.0
8	1st Coma X	6	0.08	1	0.1
9	1st Tref Y	31	0.39	5	0.1
10	1st Tref X	10	0.13	3	0.0
11	1st Sper	18	0.23	1	0.2
12	2nd Ast X	25	0.31	1	0.3
13	2nd Ast 45	5	0.06	1	0.1
14	1st Tetr X	21	0.26	1	0.3
15	1st Tetr Y	5	0.06	3	0.0

* Note: Active Isolation results are estimated using scale factors based on LMCO test results for reduced systems. Elliptical Zernikes were used for fitting, WFEs are RMS values.

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Steady state thermal effects

180 degree roll of spacecraft

Thermal Model

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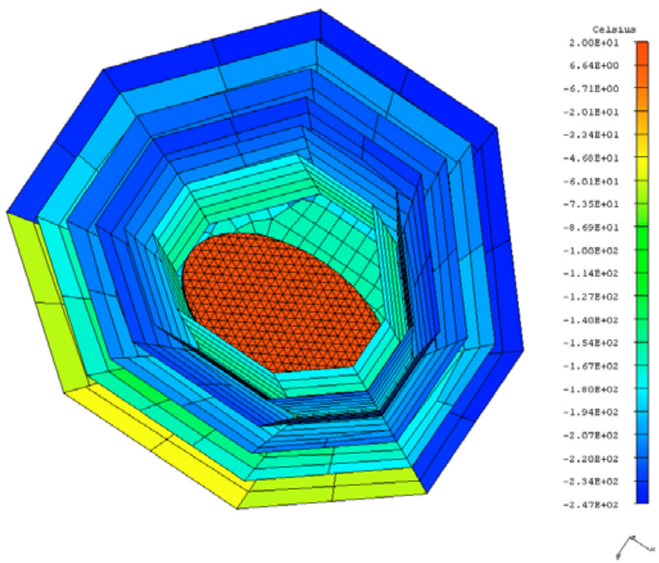

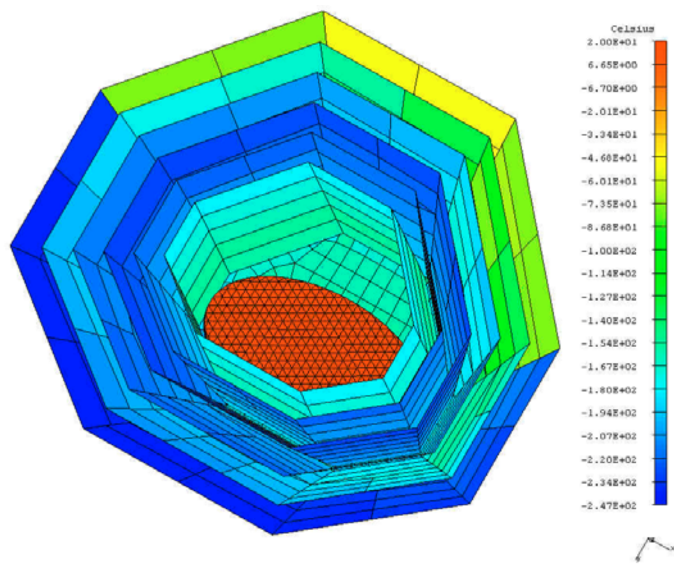

Steady State Thermal Analysis of Sunshield and Primary Mirror

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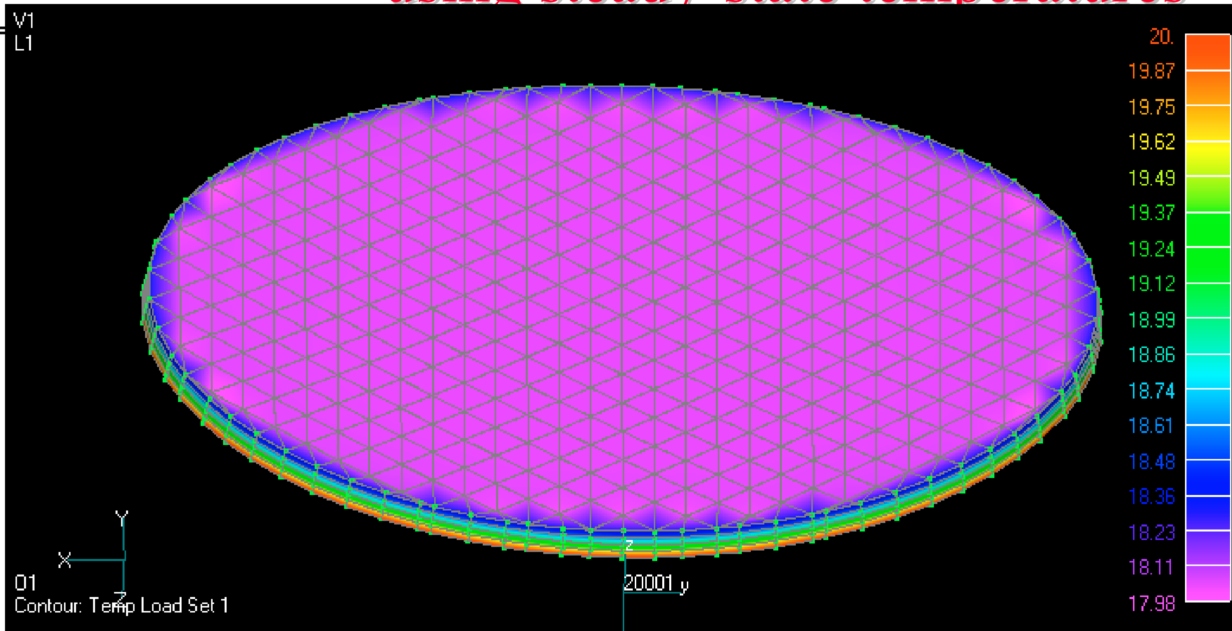
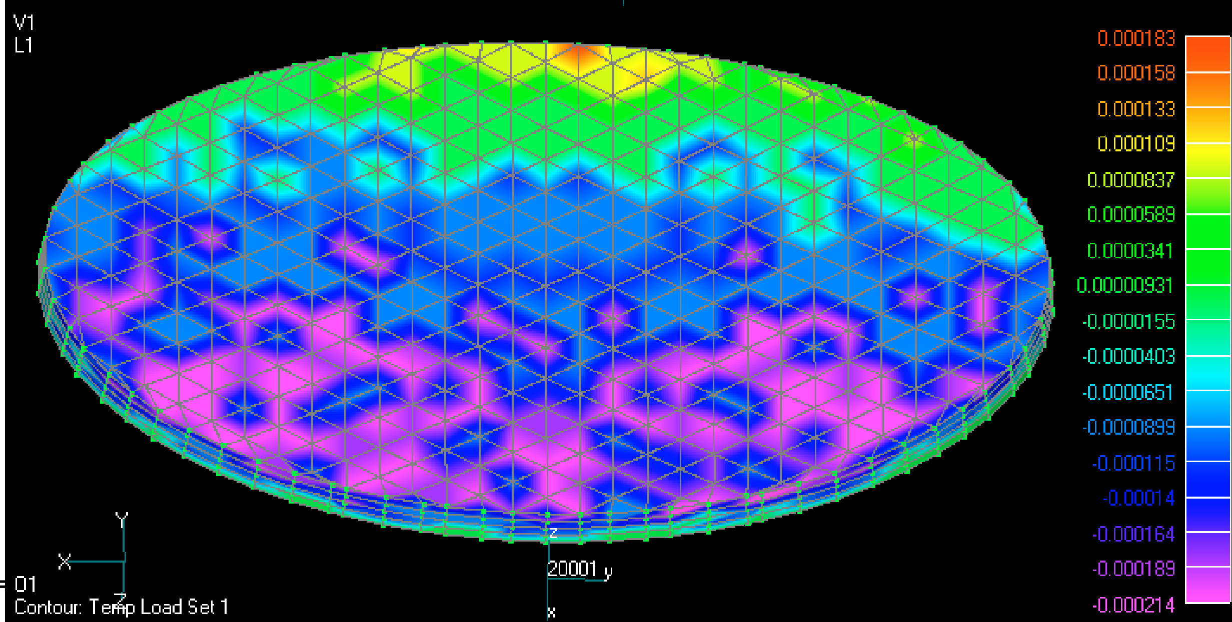
Thermal Analysis of 180 degree roll using steady-state temperatures



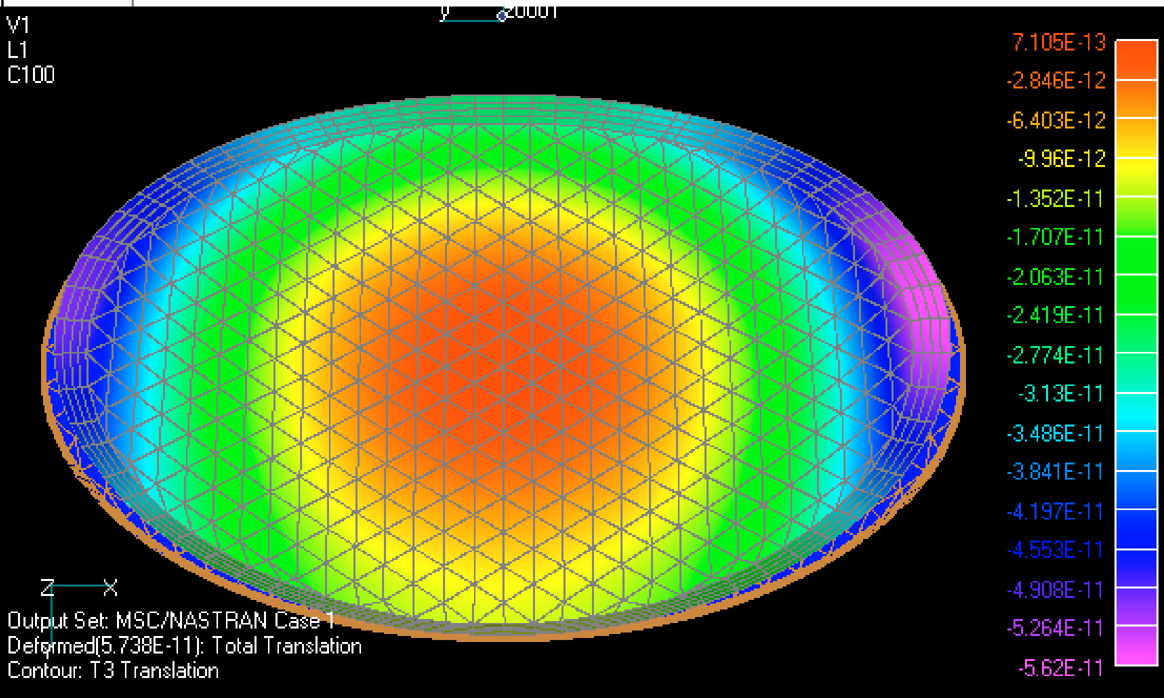
Pre-Roll Steady-State Temps for Beta= 90 deg and Sun at -Y Position



Steady-State Delta Temps for 180 deg Roll from -Y to +Y Orientation (~+- 0.2 mK Change)

Notes: Thermal model used includes mid-fidelity primary mirror (smeared core props) and 6 v-groove layer sunshield. Secondary mirror & support struc not included.

Structural response of 180 degree roll using steady-state temperatures



FEM Displacements Highly Magnified and
Z-disp Contours for Steady-State Delta Temps
(Beta= 90 deg, ~Surface RMS WFE = 25.6 pm)

Breakdown of FEM Displacements into Zernike Components (see Notes below)

Zernike	Descr	WFE	Req	WFE/Req
4	Power	22.80	5	4.6
5	1st Ast 45	0.35	10	0.0
6	1st Ast X	13.00	5	2.6
7	1st Coma Y	2.54	10	0.3
8	1st Coma X	0.52	1	0.5
9	1st Tref Y	6.20	5	1.2
10	1st Tref X	0.28	3	0.1
11	1st Sper	0.17	1	0.2
12	2nd Ast X	0.55	1	0.6
13	2nd Ast 45	0.04	1	0.0
14	1st Tetr X	0.41	1	0.4
15	1st Tetr Y	0.17	3	0.1

Notes: Tabulated Zernike WFEs are RMS values computed using elliptical Zernike functions, and PM displacements times 2 (rather than from the propagated sensitivity results)

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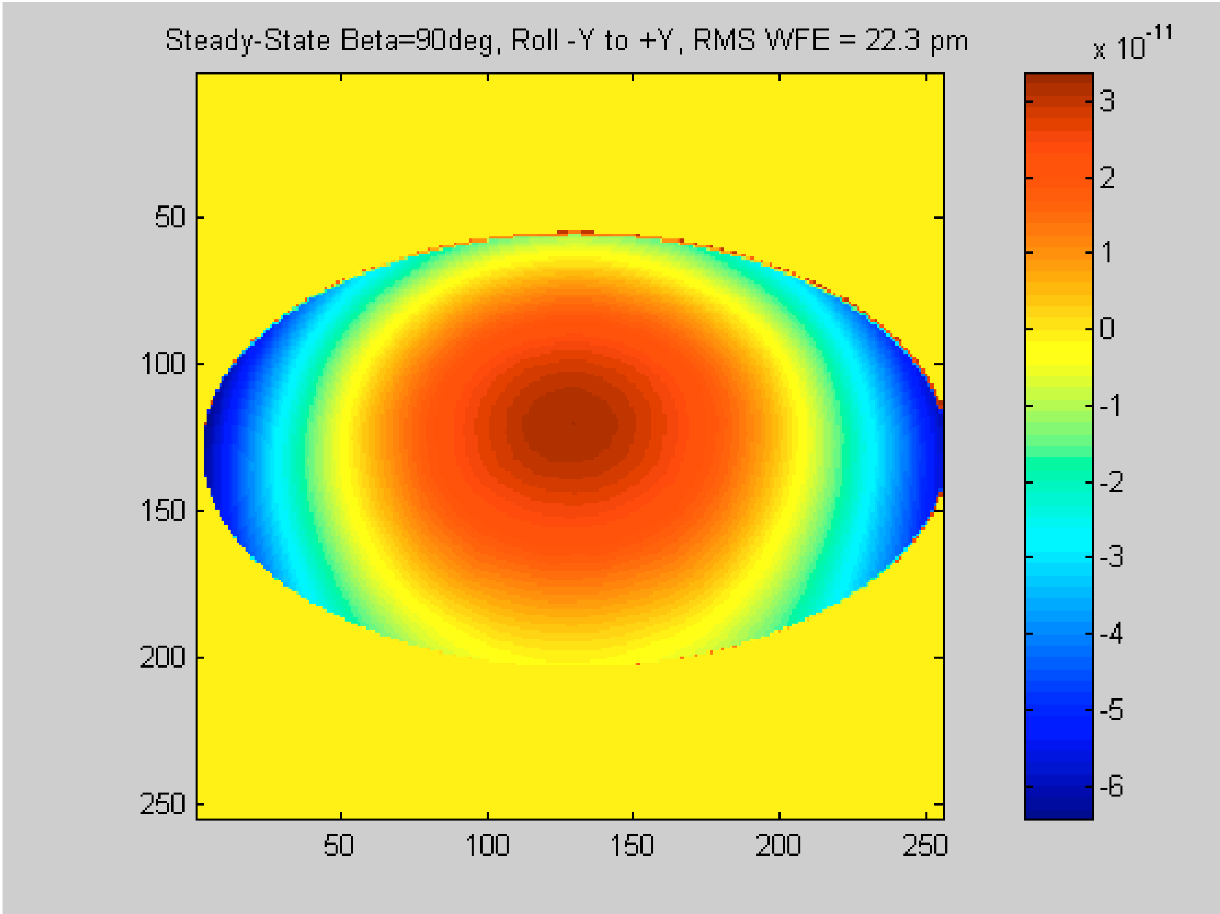
Optical response of 180 degree roll using steady-state temperatures



OPD Map from PM Sensitivity Matrix for Response to 180 deg Roll (Beta=90) Using Steady-State Temperatures

Final thoughts

- Results are preliminary--we've spent a lot of time carefully building up and verifying our modeling capabilities, but not much time with the TPF design yet.
- We have the capability of performing full near-field diffraction analysis to better analyze the wavefront at the coronagraphic mask and the overall contrast ratio at the detector.
- We will soon have the capability of quickly estimating contrast (for a particular coronagraph design, i.e. mask and Lyot stop) versus structural deformations, rather than looking only at wavefront. This will speed up structural and thermal optimizations.